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PRELIMINARY NUMERICAL SIMULATIONS OF INFRASOUND GENERATION PROCESSES BY SEVERE WEATHER USING A FULLY COMPRESSIBLE NUMERICAL MODEL

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1. INTRODUCTION

Recent measurements with near infrasound detection systems are suggesting a significant potential for improving tornado warnings. There appears to be a strong connection between pressure fluctuations monitored in the frequency range 0.5 to 10 Hz and the occurrence of tornadoes (Bedard and Georges 2000; Bedard 2004). The goal of this numerical modeling study is to determine the generation mechanisms responsible for the infrasound emanating from tornadic storms. One possible mechanism for tornadic generation of infrasound is radial modes of vibration of the vortex core. Abdullah (1966) developed a mathematical model for a Rankine vortex and obtained solutions for radially symmetric vibrations. The fundamental frequency f was found to be given by

$$f = \frac{207}{a} \qquad (1)$$

where a is the radius of maximum winds measured in meters. For a radius of 200 m, this equation predicts a frequency of ~1 Hz. Bedard (2004) contrasted various possible generation mechanisms and found that the radial vibration model is most consistent with the infrasonic data. Another possible mechanism that could generate infrasound of ~1 Hz is latent heat release. As an air parcel is heated and it expands the adjacent air is compressed, which generates an infrasonic wave. Nicholls and Pielke (2000) simulated a very low frequency Lamb wave produced by a convective storm and noted that higher frequency waves with periods on the order of tens of seconds also occurred. In this study, we investigate if even higher frequencies of order 1 Hz can be produced by this mechanism.

Simulations are performed with a fully compressible three-dimensional numerical cloud model. A non-supercell type tornado storm is simulated and preliminary analyses are conducted to determine the infrasonic generation mechanisms.

2. MODEL DESCRIPTION

A two-way interactive, nested grid version of the Colorado State University Regional Atmospheric Modeling System (RAMS) is employed (Pielke et al. 1992; Cotton et al. 2003). Two grids are used with horizontal grid increments of 200 m and 50 m and with (x,y,z) dimensions of 80 × 80 × 73. The vertical grid increment is 25 m at the surface and is gradually stretched to the top of the domain at 30 km. A 15 km deep Rayleigh friction layer is included to absorb vertically propagating compression waves and gravity waves. A radiative boundary condition is applied at the lateral boundaries of the coarse grid to prevent reflection of infrasonic waves. For this preliminary simulation, only the cloud water microphysical category was activated. The model was initialized with a low-level vortex in cyclostrophic and hydrostatic balance. Maximum wind speeds were 12 m s^{-1} at a radius of 3 km. The environment was quiescent with a large amount of convective available potential energy. A warm bubble centered at a height of 1.5 km above the surface was initiated by prescribing a heat source for the first 100 s of simulation time.

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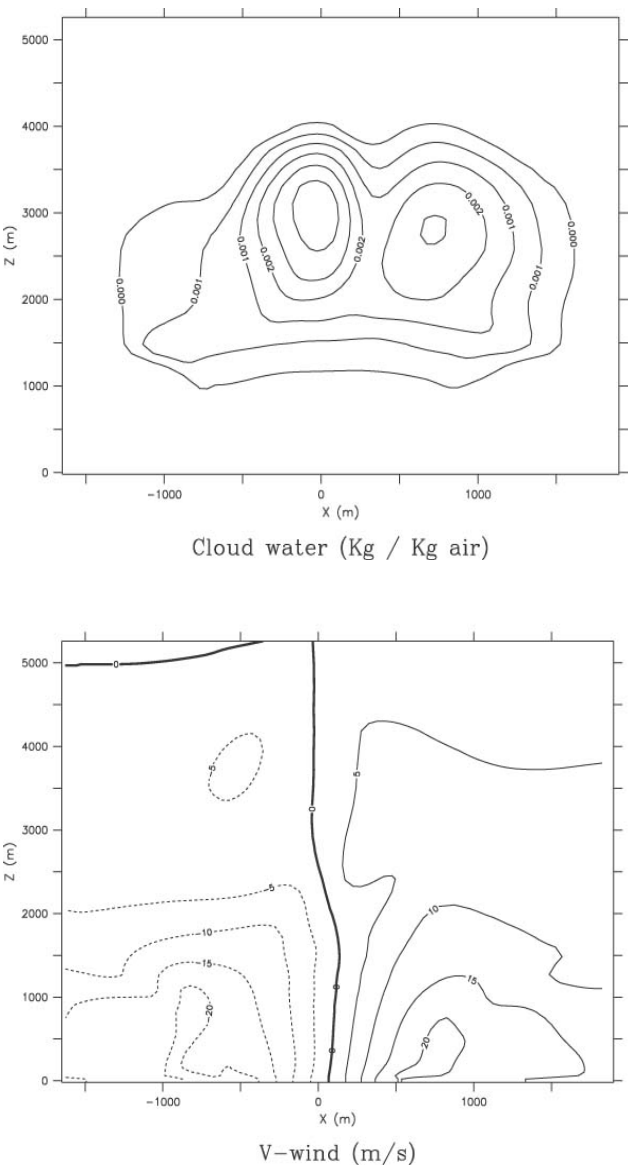

Figure 1: x/z sections at 240 s (top) Cloud water mixing ratio. The contour interval is 0.001 kg/kg. (bottom) y-component of velocity. The contour interval is 5 m s^{-1}.

3. RESULTS

Figure 1a and b shows an x/z section off cloud water mixing ratio and y-component of velocity, respectively at = 240 s. A cloud is developing above the misoscale vortex that has maximum wind speeds of ~20 m s^{-1}. Figure 2a and b shows the fields at t = 600 s. A condensation funnel has formed and the vortex has strengthened to ~35 m s^{-1}.

Figure 3 a, b, and c shows time series of the surface pressure perturbation at 1.5 km from the center of the storm. In Fig. 3a, two spikes are evident near the beginning of the simulation and just after 100 s. These are due to the low-level heat source that was applied for 100 s. This structure is consistent with results

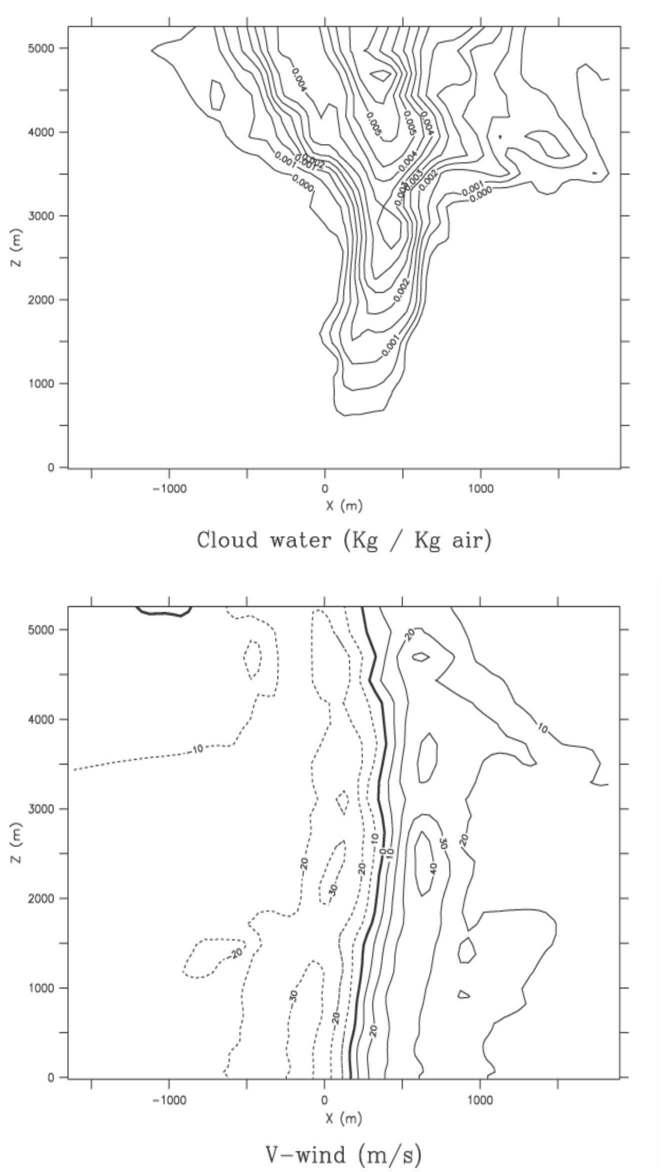

Figure 2: x/z sections at t = 600 s. As in Fig. 1.

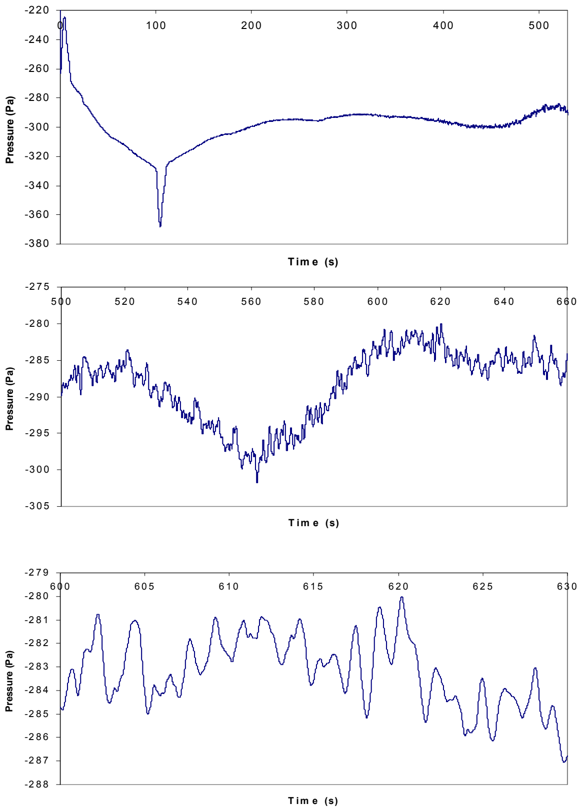

Figure 3: Time series of the surface pressure perturbation at 1.5 km from the center of the storm for (a) t = 0-600, (b) t = 500-660 s, and (c) t = 600-630 s.

obtained using a simple linear compressible model (Nicholls and Pielke 2000). Significant high frequency fluctuations occur after 400 s. Figure 3b shows more details of these high frequency fluctuations between t = 500-660 s and Fig. 3c zooms in further on the interval t = 600-630 s. The amplitude of the wave is about 2-3 Pa and the period about 1.5 s. Measurements suggest amplitudes of approximately 10 Pa at this distance from storms that generated strong tornadoes. Therefore, this modeling result from a weak tornadic storm seems reasonable.

Further analysis indicates that the waves propagate at the speed of sound. A simulation of a storm without the initial low-level vortex did generate infrasound, but with significantly lower frequency. A simulation was also conducted that was initialized with a strong vortex of ~60 m s^{-1}, but without microphysics activated and a warm bubble. The vortex was perturbed from cyclostrophic balance by increasing the tangential wind speed by 5%. This produced high frequency waves of ~1 Hz that may have been due to radial vibrations of the vortex. However, this does not appear to have been the main mechanism responsible for the generation of infrasound in the tornadic storm simulation. An identical tornadic storm simulation conducted with the standard version of RAMS that allows mechanically generated acoustic waves, but not thermally generated, did not produce significant high frequency infrasound. This suggests that the main generation mechanism for the tornadic storm simulation was small-scale latent heating fluctuations. The occurrence of the high frequency infrasound coincided with the development of considerable small-scale turbulence that may have caused small-scale latent heating fluctuations. Simulations of tornadoes conducted by Lewellen et al. (1997), also showed the development of strong turbulence. There is also the possibility that vibrations of a vortex could modulate small-scale latent heating fluctuations.

4. CONCLUSIONS

A simulation of a non-supercell tornado storm was conducted and infrasound was generated within the lower end of the frequency range that shows potential for detecting tornadoes. Analysis suggests that the main mechanism responsible for generating the infrasound in this simulation was small-scale latent heating fluctuations. However, high frequency infrasound was also obtained by perturbing a strong vortex, which may have been through the radial vibration mechanism. Since the tornadic storm simulation produced a weak tornado, had limited resolution, simplified microphysics, and used a quiescent environment, it is too early to say what the relative contribution of latent heating fluctuations is, compared to other mechanisms, such as radial modes of vibration. Nevertheless, these results suggest that at least for infrasound generated at the lower end of the monitored frequency range, latent heating fluctuations may make a significant contribution.

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